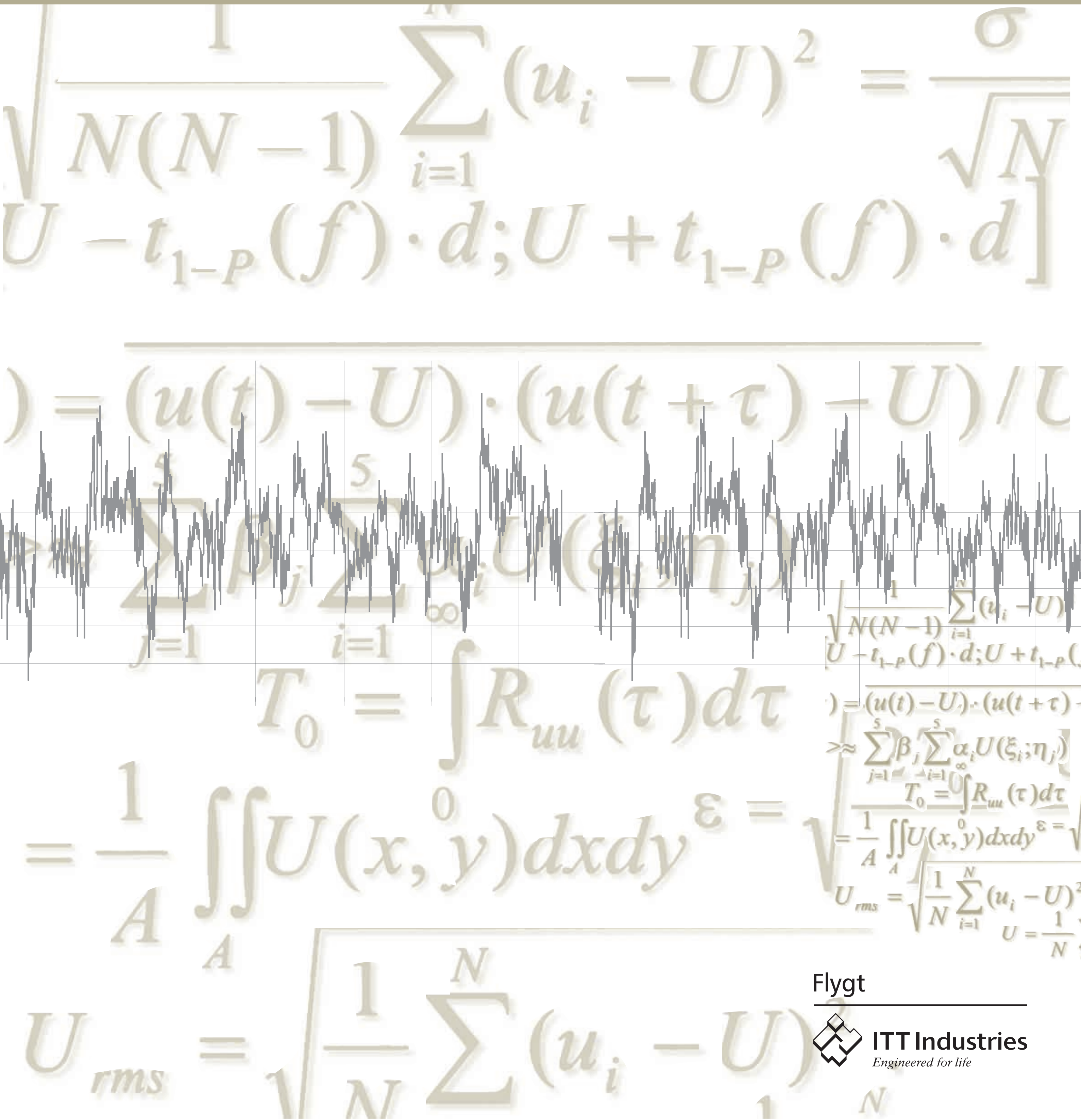
Velocity measurements

Guide and theory



Flygt

ITT Industries
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Velocity measurements in mixer applications

Abstract

Velocity measurements in mixed tanks provide information to both user and mixer supplier about the performance of mixer installations. As measurements can be carried out and evaluated in very different ways, a standardised way of acquiring, evaluating and reporting the velocity data is needed. A method for measuring velocity in tanks of the circulation channel type is described. The same principles hold in circular tanks with horizontal bulk flow.

The influence of the required accuracy on the measurement time and the number of measurements is addressed. Evaluation of average velocity and other entities across a section is made with high accuracy using the Gauss-Legendre Quadrature Scheme (GLQS).

Velocity measurements can be made efficiently with an Acoustic Doppler Velocimeter (ADV) connected to a computer for data storage. Other equipment, such as an electromagnetic sensor, may be used but will yield less precise results.

A computer program developed by ITT Flygt facilitates the velocity measurement process and the evaluation and presentation of the results. A suggested velocity guarantee text is provided at the end.

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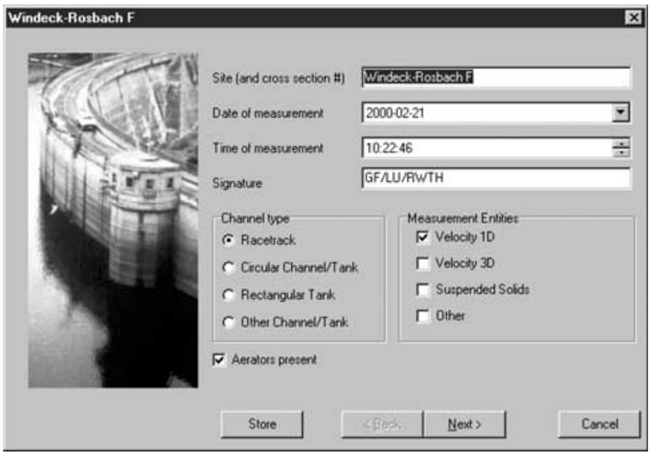
1. Quick guide

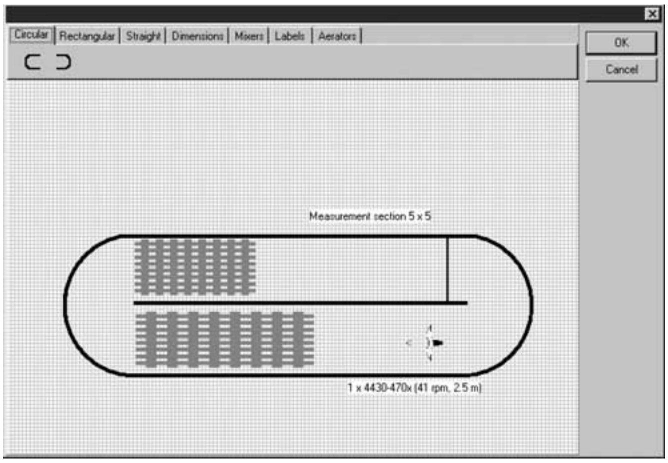
This guide assumes the user to be familiar with the practical handling of the measurement equipment and the ITT Flygt PC application “Mixing Measurement Assistance” (MMA). The details of each are given in the respective manuals [1, 2].

A. Preparatory work

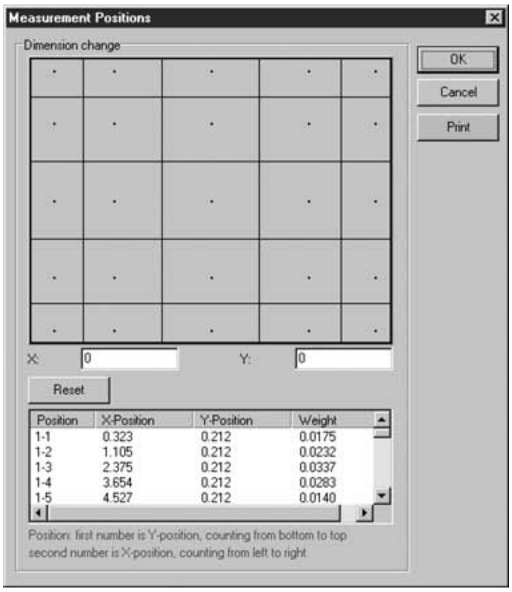
This part may be possible to complete before visiting the site, if enough information is at hand. If dimensions etc. must be collected on site, most of the data is easily entered directly into the MMA program. Supplementary input, such as a sketch, may be added at any later time.



1 Site/tank/mixer/aeration data is collected and entered into MMA. MMA works with only one measurement cross section (MXS) per report, but there is an edit facility to generate several similar reports. Note that several measured entities, such as velocity *and* suspended solids concentration, can be collected in the same report if they are measured at the same points.



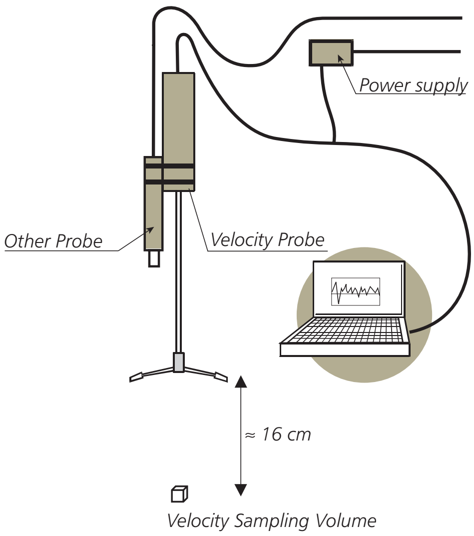
2 The location of one or several MXS is defined according to practicability (access) and the guidelines in Sec. 3 regarding clearance to flow disturbances. A simple draw utility in MMA (Tank overview) may be used to produce a clear sketch of the tank, the situation, etc.



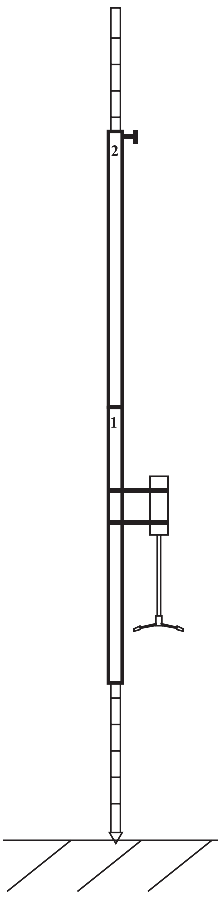
3 The MXS grid is defined in MMA. The default given by the program is a Gauss-Legendre Quadrature Scheme. Typically 5 x 5 points is recommended. If, on site for instance, practical limitations make it necessary, the grid can easily be redefined. A printout of the measurement locations is convenient to bring to the measurement site.

B. Measurement – on site work

4 Mark the horizontal positions of the measurement points at the cross section, e.g. by putting tape on the fence or tank wall etc. This facilitates the positioning of the rod system, cf. item **6** below.



5 The measurement equipment is mounted and started according to the equipment manual, cf. item **7** below. First note that if more than one entity is to be measured, consider putting several probes together. For instance, a Solids Suspension probe can be taped onto the body of a velocity probe. Make sure there is minimum interference between the probes. (E.g. the suspension probe should not disturb flow that goes into the measurement volume of the velocity probe.) This unfortunately affects the accuracy of the cross section average calculation of the additional quantity (Solids Suspension), since the very same horizontal and vertical coordinates typically will not be covered by this probe. It is recommended to keep this coordinate deviation as small as to within approximately 0.35 m.



6 The rods of the probe positioning system are joined to a length which corresponds to the distance from the tank bottom to the height where the rod system is to be held/fixed. The velocity probe is mounted on the first (lowest) pipe of the probe positioning system. The pipe is put to slide on the rods. Pipes are joined to enable the probe to slide down to the correct measurement depths. The uppermost (or second uppermost) pipe is always held/fixed (it is also fixed to the rod by a screw). The length scale on the rods helps keeping track of the centimetres. The pipes are numbered, so by using them in correct order, it is easy to keep track of the metres as well.

7 The Nortek ADV may be started as follows:

7I Connect the ADV power cable to the power supply and the signal cable to the computer.

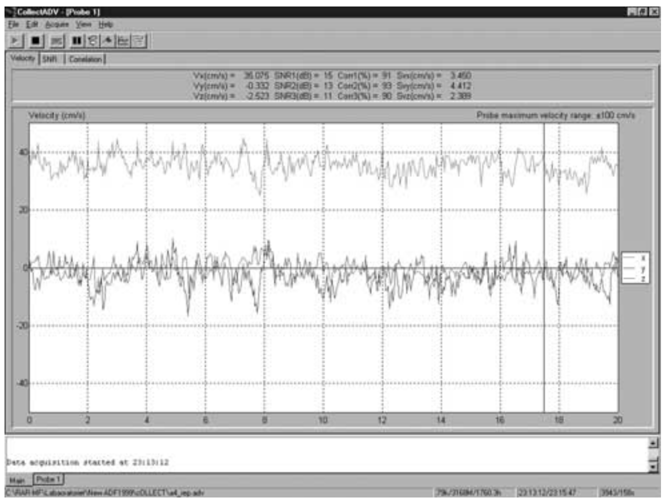
7II Turn on the computer.

7III Run the ADV program (double-click the "Vector" icon.)

7IV Fill in the relevant data. **NB!** This is the only place where sampling rate and velocity range can be set.

7V To save the measurement in a data file, enter its name at "Record To File". As explained in the MMA manual, the file name should be of the type *site-mxs-11.adv, site-mxs-21.adv* etc, for instance *Grums-1-11.adv*. The numerals denote the row and column in which the point is situated, counted from lower left. All files, e.g. *site-mxs-11.adv – site-mxs-55.adv* must be present before automatic reading into MMA for processing and reporting. (If the measurement is made with manual reading of data, this may be directly entered into MMA.)

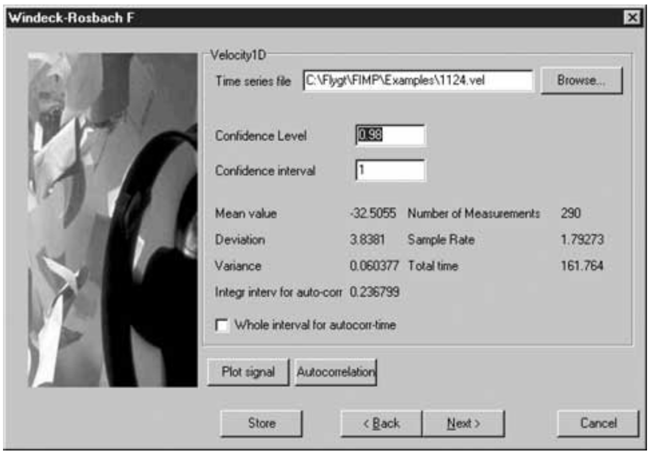
7VI The ADV "Probe Adjustment for boundaries" will appear. To start the measurements, press the "Start Disc Recording" icon.



7VII Real time data will then be displayed on the screen. **NB!** If no file name was specified under "Record To File", the data will not be saved and will be unrecoverable. The measurement stops when the "Stop Disc Recording" icon is pressed.

8 If ADV time series data are recorded to file, assess the required measurement time for each point as follows. If a time series is not recorded, 2 minutes should be used for sampling/averaging.

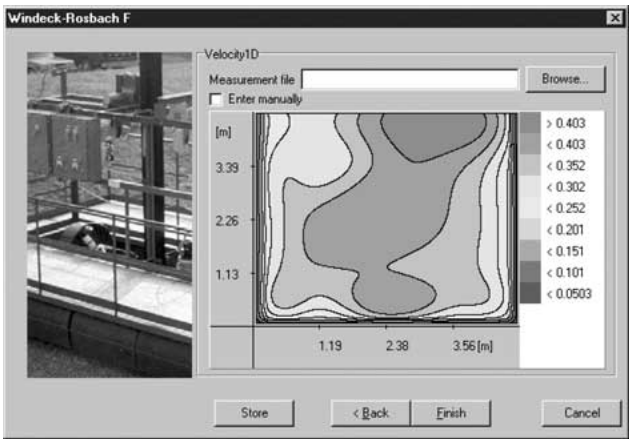
8i Record a long series, preferably 10 minutes, of a velocity measurement in a point close to the surface and close to the wall. If the usual 5 x 5 grid is used, select the point 51 or 55 for this measurement, and save the data accordingly, e.g. in the file *site-mxs-51.adv*.



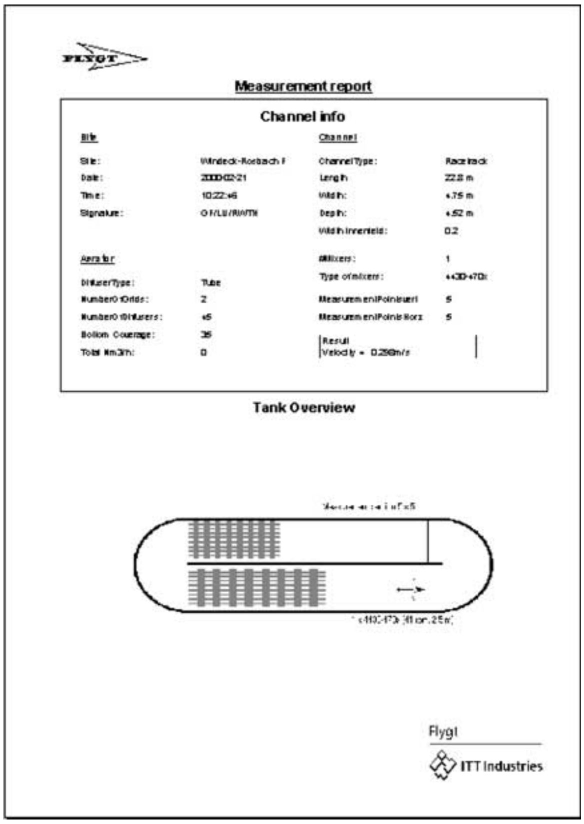
8ii Open this file from within the "Time Series Assessment" menu in MMA (which appears after the administrative menus for a case). For suitable values of the confidence level (95 %) and the confidence interval (±1 cm/sec), the required minimum sample rate and the required total measurement time per point are given by MMA.

8iii Using the sampling rate and measurement time obtained in 8ii, measure at the rest of the points (cf. item **7iv**) above.

C. Evaluation and report



9 Enter the measured data into MMA either manually or automatically from the .adv files, and save the case.



10 All administrative data, the measurement grid, and the resulting data, including cross section averages, will be presented in the report printout from MMA.

11 The result data may be exported from MMA to an external *.fmp* file, which can be shared with others who use MMA. For instance, a global measurement database is built up of all *.fmp* files e-mailed to staff at the Public Utility Treatment at ITT Flygt HQ.

2. Introduction

Velocity measurements in mixed tanks provide information about the installed mixer capacity and how well it is used for mixing purposes. Velocity and related quantities, e.g. turbulence intensity, are parameters that link the mixer to the mixing and process results. Moreover, flow velocity is often the simplest visible parameter to use in order to judge the performance of a mixer installation. To the authors' knowledge, there are no standards developed for velocity measurements in mixed tanks nor are there any standards for how to evaluate the results of such velocity measurements. It is therefore desirable to establish a standardised method for performing and evaluating velocity measurements in mixed tanks.

The large variety of possible tank shapes motivates a division into three main types of tanks. These are:

1. circulation channels: annular tanks, racetracks or similar with a dominating channel flow
2. circular (cylindrical) tanks
3. rectangular tanks.

ITT Flygt has developed a standardised method for measurements and evaluation of velocity for circulation channels, where the flow resembles free surface channel flow, and for cylindrical tanks (tanks of types 1 and 2). Similar standards for the remaining tank type are under consideration. In cylindrical and rectangular tanks the influence of secondary currents and hydrodynamic instabilities are more dominating than for channel type tanks, which means that accurate velocity measurements in these cases requires more planning and will be more time consuming. The ITT Flygt method comprises recommendations for selecting measuring points as well as for the way in which measured data can be reduced into a few key parameters. It also sets the format for documentation to ensure uniformity of the result presentation.

3. Measurement cross section and grid selection recommendations

When the flow is of the open channel type, i.e. there exists a dominant flow direction parallel to the side walls of the tank, velocity measurements shall be carried out in at least 25 points in at least one plane, perpendicular to the main flow direction (i.e. perpendicular to the side walls). In circular tanks with an ordered circulating bulk flow along the curved wall, the same ideas hold. The MXS then extends from the wall to the tank centre. The MXS planes should be located in sections of the conduit where:

1. The cross section area is constant.
2. The flow is as developed as possible, which means that the MXS shall be preceded by a straight stretch, which is as long as possible. In circular channels/tanks, no such stretch is available.
3. The MXS is as far as possible downstream from flow disturbing objects such as bends, pillars, mixers or others. A minimum distance should also be kept upstream of such objects, to ensure that the influence of these on the flow profile at the MXS is negligible.

A sufficient number of points in both the horizontal and vertical direction of the cross section should be selected to ensure a reliable cross section average evaluation. A minimum of 5 x 5 points is generally recommended. The actual distribution of the points in the section is determined according to a Gauss-Legendre Quadrature Scheme (GLQS) [3]. With 5 x 5 points, the locations in the cross section at which measurements shall be made are shown in Fig. 1 and Table 1. If the practical limitations (concerning access etc.) to the point locations interfere with these recommendations, slight modifications are possible to make. In MMA, whole rows and columns can be moved, with a subsequent revision of the corresponding weights for maximum possible accuracy.

It can be noted that the points are more densely distributed along the channel sides and bottom, than in the interior. However, the GLQS also assigns higher weight to the interior points to ensure an accurate evaluation of the cross section average. This is further discussed in Sec. 5.2.

Because of the idealised property of the liquid surface as a symmetry surface, the vertical distribution of points is rather obtained by imagining a twice as high channel with a confining ceiling at the top, and e.g. 10 points used for the double depth. Of course, only 5 of these occur in the real situation.

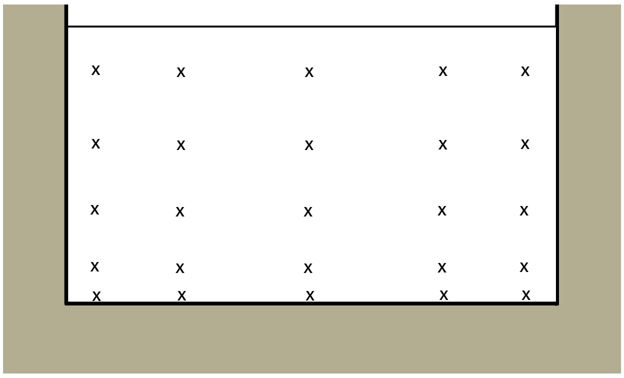


Figure 1 *Cross section of a racetrack channel. Note that the points of measurements are unevenly distributed for best quality of evaluation.*

ξ_i / W	α_i	η_j / H	β_j
0.047	0.1185	0.026	0.0667
0.231	0.2393	0.135	0.1494
0.5	0.2844	0.321	0.2191
0.769	0.2393	0.567	0.2693
0.953	0.1185	0.851	0.2955

Table 1 *The positions and corresponding weights recommended for maximum cross section average accuracy. ξ_i is the i^{th} position in the horizontal direction and α_i is the corresponding weight. W is the width of the cross section. Similarly, η_j, β_j, and H describe the set up in the vertical direction.*

4. Measurement and assessment of time series

4.1 Procedure

The velocity in a measurement point varies from moment to moment in a way that usually justifies the use of basic statistic and probabilistic methods for characterisation of the data. With an ADV probe, the velocity can be recorded several times per second. The whole series of velocities measured in a point during some time interval is called a *time series* of the velocity. An example of such a series, or *signal*, is shown in Fig. 2. It is very common that if the velocity data are collected in a histogram, the distribution of velocities takes on the Gaussian form characteristic for independent data stochastically distributed around a mean value. In Fig. 3, such a distribution from a measurement in Denmark is shown. The average value and the standard deviation (σ) provide a description of the average velocity conditions in a point.

When a time series exhibits this behaviour, one expects that an increase of the data set will make it converge to a perfect Gaussian distribution with a certain true average value, the expectation value, and with a true standard deviation. It is reasonable to require of a time series, that its average to a certain probability P (say 0.97 = 97%) is at most a number I (say 1 cm/s) different from the true *expectation value*. By stating the two values P and I, the correspondingly required number of data in a time series can be inferred, if a relatively long time series is already present. The procedure for doing this is described below. It is automatically performed by the program MMA.

There is, however, another restriction to put on the data sampling. If the data in a point are recorded too often, the velocity does not have time to change to a new "independent" value. Hence if two data are recorded within a very short interval, they may only count as one in the above mentioned statistical analysis. If for instance the velocity is periodic with a period of 1 minute, measuring 1000 values during totally 1 second will not yield a representative set of data. The time needed to elapse between two recordings is called the *autocorrelation time* (or *macro time scale*), and the procedure for calculating it given a test time series, described below, is also incorporated into MMA.

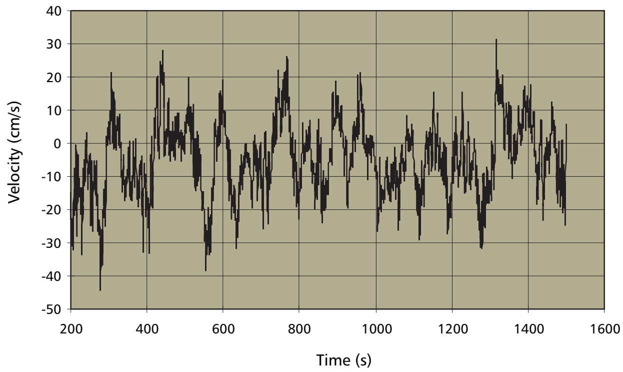


Figure 2 *Velocity at a point in the longitudinal direction of a circulation ditch 180 m long, 5 m deep and 7 m wide in a sewage treatment plant in Austria. 6500 observations were obtained during a time period of 1300 seconds.*

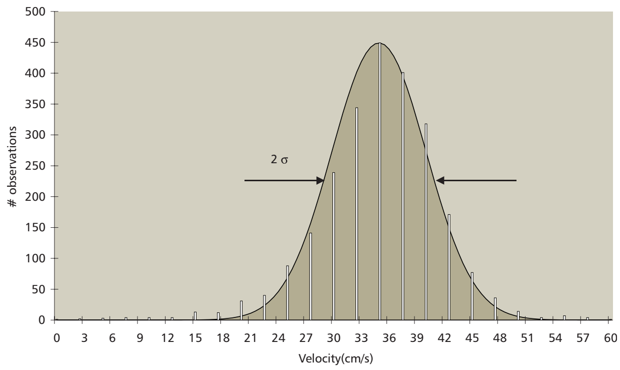


Figure 3 *Velocity distribution (bars) of a time series obtained in a circular tank in a sewage treatment plant in Denmark. 5 measurements were made every second (sample rate 5 Hz) during 8 minutes. The average value is 35.2 cm/sec. Two standard deviations (2 σ) equals the width of the distribution at half maximum. With some 2400 values, the Gaussian character (filled area) clearly emerges.*

4.2 Theory [4]

The natural way of treating a data series like the above is to calculate the arithmetic mean of all velocity observations (the sum of all velocity observations divided by the number of observations.) Mathematically this is expressed as:

$$U = \frac{1}{N}\sum_{i=1}^{N} u_i \qquad (4.1)$$

where U is the arithmetic mean, N is the number of observations and u_i is the momentary velocity. It can be shown that this is a good, normally the best, estimate of the true mathematical expectation of the underlying stochastic variable. It is interesting to note what would happen if we split the data series in Figure 2 into two equally long series and calculated the arithmetic mean for each of them. The arithmetic mean of the whole series is -4.76 cm/s, whereas the arithmetic mean of the first and second half series are -5.61 cm/s and -3.90 cm/s respectively. This rather large difference remains even though the number of observations and the observation time of even the half series are impractically large. This calls for a statement of the interval in which the estimate of the real mathematical expectation of the underlying probability distribution is likely to be found with some before-hand given probability. With the assumption that the individual measurements of the velocity u can be regarded as observations of independent stochastic variables with unknown expectation and standard deviation values, it can be shown that the true mathematical expectation with probability P will be found in the interval

$$\left[U - t_{1-P}(f)\cdot d ; U + t_{1-P}(f)\cdot d\right] \qquad (4.2)$$

where $t_{1-P}(f)$ is the 1 - P percentile of Student's t-distribution with f degrees of freedom, and d is the experimental variance defined below. The Student's t-distribution is tabulated in most statistical handbooks, and is automatically calculated by MMA. f is equal to N - 1, and d is found from:

$$d = \sqrt{\frac{1}{N(N-1)}\sum_{i=1}^{N}(u_i - U)^2} = \frac{\sigma}{\sqrt{N}}. \qquad (4.3)$$

For the time series in Figure 2, d equals 0.13 cm/s. In words this means that with a probability P the true expectation of the underlying distribution is within the interval given by equation (4.2). For example, with P equal to say 95%, $t_{5\%}(f = 6500)$ (f taken from Fig. 2) is found from a statistical table to be 1.96. Hence in 19 cases out of 20 (= 95%) the true expectation value can be expected to be found in the interval (-5.01; -4.51) cm/s. Generally, the width of the interval can be reduced by increasing the number of observations and thus the measurement time.

In a dynamic system like a mixed tank we also have a requirement on a sufficiently long measurement time. (If it is desired to perform a frequency analysis of the velocity signal, the dynamics of the mixed tank also puts a requirement on the longest acceptable time between two consecutive measurements. In such a case the Nyquist criterion states that one has to sample the signal with at least twice the highest frequency component of the signal.) The length of the required measurement period is linked to the relative uncertainty ε of the estimate of the average velocity through

$$\varepsilon = \sqrt{\frac{2T_0}{T}}\,\frac{U_{rms}}{U} \qquad (4.4)$$

where T_0 is the macro time scale of the system, T is the total measurement time, U_{rms} is the root mean square of the velocity signal and U is again the time averaged velocity signal. The relative uncertainty, ε , is defined as the variance of the experimental mean normalised with the average velocity.

Both the Macro time scale T_0 and U_{rms} can be found from a velocity signal. First,

$$U_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(u_i - U)^2}\,. \qquad (4.5)$$

For large values of N, $U_{rms} \approx \sigma$. T_0 can be found from the autocorrelation function of the velocity signal. The autocorrelation function R_{uu} is defined as:

$$R_{uu}(\tau) = \overline{(u(t)-U)\cdot(u(t+\tau)-U)}\,/\,U_{rms}^2 \qquad (4.6)$$

where τ is a separation variable; $u(t)$ is the momentary velocity at time t, and $u(t+\tau)$ is the momentary velocity at time $t + \tau$. Overbar means time averaging. In words, the autocorrelation function is the time average of the signal multiplied by itself but shifted a time interval τ.

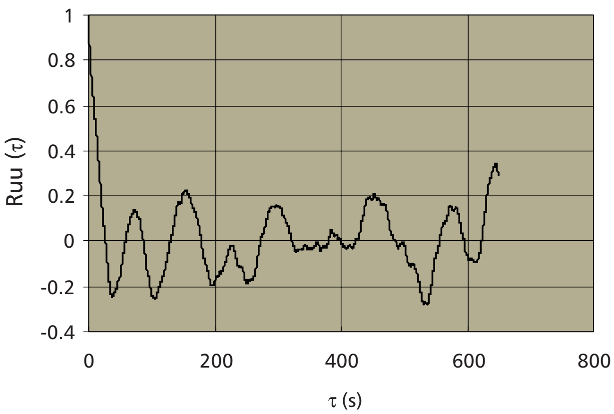


Figure 4 *A plot of the autocorrelation function $R_{uu}(\tau)$ as a function of the separation variable τ.*

Finally the macro time scale can be found from the autocorrelation function according to:

$$T_0 = \int_0^{\infty} R_{uu}(\tau)d\tau. \tag{4.7}$$

(In practice, the integral is often evaluated from 0 to the first zero of R_{uu}, which is likely to be conservative for the present purposes.) T_0, which is a measure of the longest time scales in the turbulent flow field, can be used in Equation (4.4) to find out the required measurement time T in order to get the average velocity with a relative uncertainty less than ε. For the example above the Macro time scale is about 10 s. Using Equation (4.4), it becomes evident that an uncertainty (defined as the variance of the experimental mean) less than 0.13 cm/s, requires over 40 hours of measurement, which is quite an unrealistic operation. If, however, one can accept an uncertainty of 2.0 cm/s, the required measurement time, instead, is about 10 min, still prohibitive if one considers that some 30 points are to be measured in one measurement section. While the example given here is, as stated above, extreme, it serves well as an illustration of the precautions that have to be taken when a seemingly simple thing such as an average velocity is to be measured. In more common cases, the macro time is substantially shorter.

5. Velocity and fluxes through a cross section

5.1 Required values – background

In many mixer applications a certain value of the flow velocity is specified. Since the velocity varies from point to point and from moment to moment, a time and space average value is the simplest to specify. In some cases, a true net transport of liquid from A to B, or around a circulation ditch is required at a certain rate. Then the average transport velocity is the obvious candidate.

Often, some velocity is stated with reference to the mixing duty of sediment avoidance and related results. In *WWTP*s, a value of 0.3 m/s (1 ft/sec), or sometimes up to 0.35 m/s or higher, or down to 0.22 m/s or even lower is specified. These figures are based on experience and initially emerged from an analogy with sewage or slurry pumping. The reasons for the variation of this value are the different characteristics of waste water, differences in pretreatment in *WWTP*s, differences in conditions in the tank (e.g. presence of pipes along the bottom, which hinders the flow and promotes settling), and differences in additional mixing requirements that may or may not be expressed. The *bulk flow velocity* as defined below is actually required to have larger values in deeper tanks, but this is rarely considered.

Since this velocity requirement refers to local conditions, i.e. in a major part of the tank or channel, the direction of the flow is of minor importance, and the magnitude of the velocity can be considered to be the relevant parameter for mixing. Still, typically one or a few main circulation loops are generated with submersible mixers. Therefore, there is an indication of a way of selecting a measurement cross section where a representative tank average value of the velocity can be found. The net transport velocity (responsible for the volumetric flux) across such a section is of the same order as the total velocity magnitude – hence measuring only the velocity component perpendicular to the cross section gives a good hint of the prevailing average velocity. The average velocity across a correctly selected section is generally termed the *bulk flow velocity* – and mixer sizing and positioning is most commonly based on a required value of this.

Rarely does one encounter specifications for other flow variables than the velocity – even in heat transfer applications, requirements are often translated into a velocity. However, it may be that the velocity is sometimes required to attain a minimum (or maximum) value at certain points of the tank. For instance, a minimum velocity of 0.15 m/s at 10 cm from the bottom might be specified. Such specifications are tricky to deal with, as local variations will always be present, although the mean velocity may be very high. Literally fulfilling this requirement leads to excessive sizing for the actual mixing duty.

Once velocity measurements have been made in a cross section, one can derive kinematic information other than just the average velocity. This includes momentum and kinetic energy flux across the section. When there is a thorough investigation of the flow conditions, these entities can shed light on the total situation. Normally, though, they are of little interest. An exception might be the momentum flux, which actually contains the value of the *bulk flow velocity* which mixer sizing is really based on. This may differ by some amount from the value arrived at according to the procedure adopted in this handbook. Therefore, when a velocity is to be guaranteed, rather than the mixing duty this velocity is supposed to effect, special care should be taken. In ITT Flygt's Mixer Dimensioning System, MiDS, there is a function for sizing mixers to guaranteeing velocities.

5.2 Cross section average evaluation – theory

The natural procedure for time and space averaging of the velocity consists of first finding the time average in each measurement point and then calculating a space average – in this case a cross section average – of the time averages. If there were a device that measured the velocity in all points simultaneously, then one could have done the cross section averaging for every instant of measurement, and finally calculated the time average of these cross section averages.
There is no handy such device available for the moment, though.

The average velocity in a cross section, denoted by $<U>$, is given by

$$<U> = \frac{1}{A}\iint_A U(x,y)\,dxdy \qquad (5.1)$$

where A denotes cross section area and x and y are the coordinates in the plane of measurement. Using the Gauss Legendre Quadrature Scheme [3] the integral can be approximated by

$$<U> \approx \sum_{j=1}^{5}\beta_j \sum_{i=1}^{5}\alpha_i U(\xi_i;\eta_j) \qquad (5.2)$$

where ξ_i and η_j are the vertical and horizontal measurement positions respectively, and α_i and β_j are the weight factors resulting from the GLQS mentioned above. (Here, 5 locations in each direction have been assumed. A conventional factor 1/4 has been absorbed into α_i and β_j.) The same approximation of the integral can be applied to find area averages of other quantities, e.g. $<U^2>$. The reason for using the Gauss-Legendre method is that it closely approximates the integral of a not too chaotic function better than most other methods. It does not however, improve the accuracy of the function U (as opposed to the value $<U>$) or the values used to represent it. To illustrate the exactness of the method we consider two examples where the flow through a channel is to be determined. (Only one component of velocity is measured.) The velocity profiles are given by the contour diagrams in Figure 5a, generated by MMA. In the second cross section, there is flow reversal, which typically occurs close to mixers and just after racetrack bends. In Figure 5b, the application of GLQS and simple averaging with evenly distributed points is shown to produce differences in accuracy. Note that the number of measurement points is equal to the square of the number on the horizontal axis. For a very simple flow profile, there seems to be little or no gain in using the GLQS, but the stability with which this method approaches the true value as the number of points increases, is extremely valuable. In addition, as soon as a profile with more structure occurs, the gain is dramatic. As realistic profiles always contain some structure, it is easy to realise the benefit of always using a GLQS.

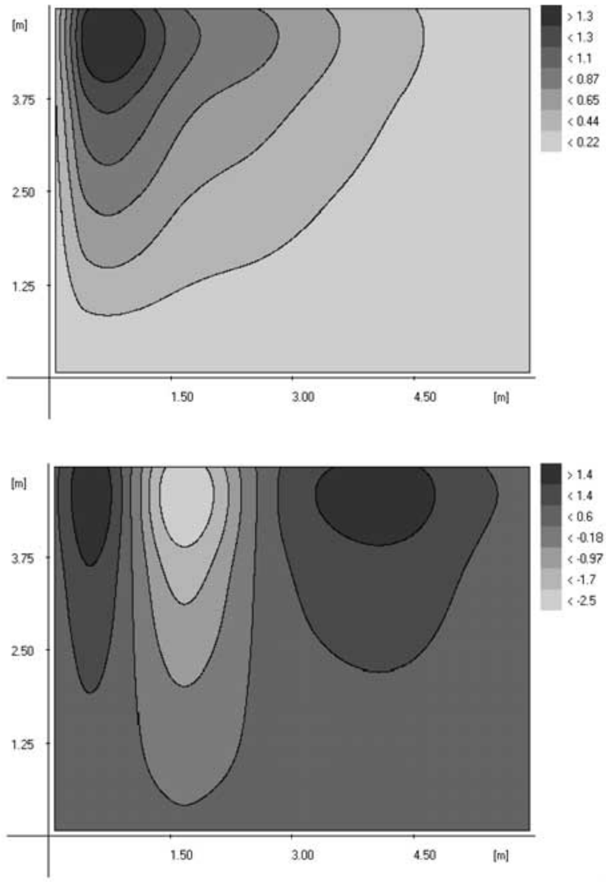


Figure 5a *Contour diagrams of two ficticious velocity profiles.*

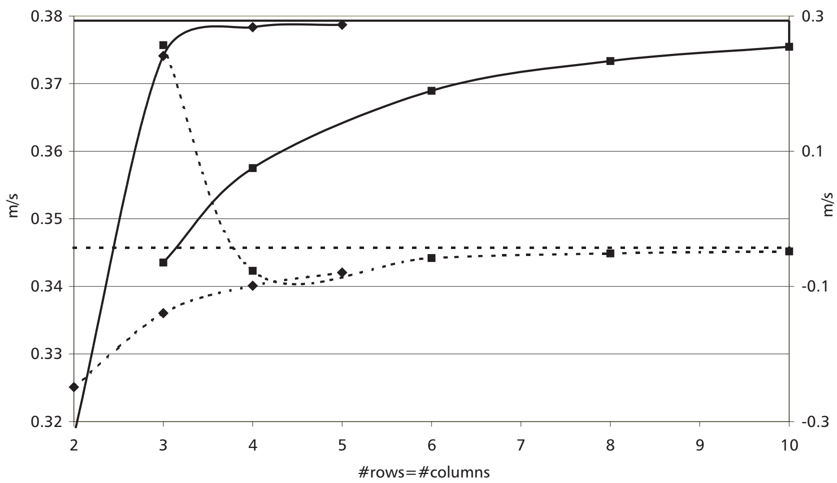


Figure 5b *Approach to true cross section average as the number of columns and rows increases. Diamonds denote GLQS values (from 2 x 2 to 5 x 5 points) and squares denote even point distribution averaging (from 3 x 3 to 10 x 10 points). Dotted lines refer to the left scale (the upper profile in Figure 5a), and solid lines to the right scale (the lower profile in Figure 5a). Lines with no symbols define the true values.*

6. Mixing Measurement Assistance (MMA) for 32-bit Windows systems

The theories and procedures outlined above for a sound measurement and evaluation of the bulk flow velocity comprise an extensive mathematical and practical apparatus. As is evident from the Quick guide (Sec. 1), much of the mathematical work has been automatised in the MMA program. In addition, a summary of administrative data such as time and place of measurement, geometry of channel/tank, and other conditions that are of interest, is made.

The average velocity (and average dry solids content, or temperature, pH or whatever is measured) is calculated, and a contour diagram of each measured quantity is produced. All this is collected in a report, where the measurement grid and the corresponding weights (cf. Table 1) also are shown. To each MXS corresponds one report, regardless of what quantities are measured. There is an extensive manual to the program [2].

7. Velocity measurement devices

Any instrument made for velocity measurements can in theory be used for the kind of measurements discussed in this paper. However, practical restrictions like accuracy, handling principles, sensitivity to clogging, measurement output format etc. restrict the variety of usable instruments. In real life mixing applications the most suitable instruments are Accoustic Doppler Velocimeter (ADV) systems or electromagnetic velocity measurement instruments. The Acoustic Doppler Velocimeter system used by ITT Flygt is manufactured by Nortek AS, Norway [1]. It is a handy and easy to use tool for velocity measurements in both laboratory and real applications. It can determine the complete velocity vector (i.e. the velocity in all three mutually orthogonal directions), in one point at a time, a feature that few other velocity measuring systems can offer. The current system can measure and store up to 64 measurements per second, which means that some characteristics of the turbulence can be determined or at least estimated. To the authors knowledge these characteristics make the ADV system the best choice for velocity measurements in mixed tanks.

The principle of operation is that the instrument emits ultrasonic beams that are reflected by small particles entrained in the liquid. The reflected sonic beams are picked up by a receiver. The frequency of the reflected sound is shifted in proportion to the velocity of the reflecting particle. The frequency change between emitted and received sound is determined by the electronics in the instrument and reported to a computer that handles the data storage.

The Nortek ADV system used by ITT Flygt consists of a probe, a power supply, and a computer with driver software to control the system, cf. Fig 6. The system may be made available to any subsidiary company of ITT Flygt.

The output from the ADV system is one data file per measuring point, containing a time series of velocity readings. Software to extract useful numbers from the time series in the ADV files is available on the computer. For a discussion of the required length and number of data points in the time series, refer to Sec. 4 above.

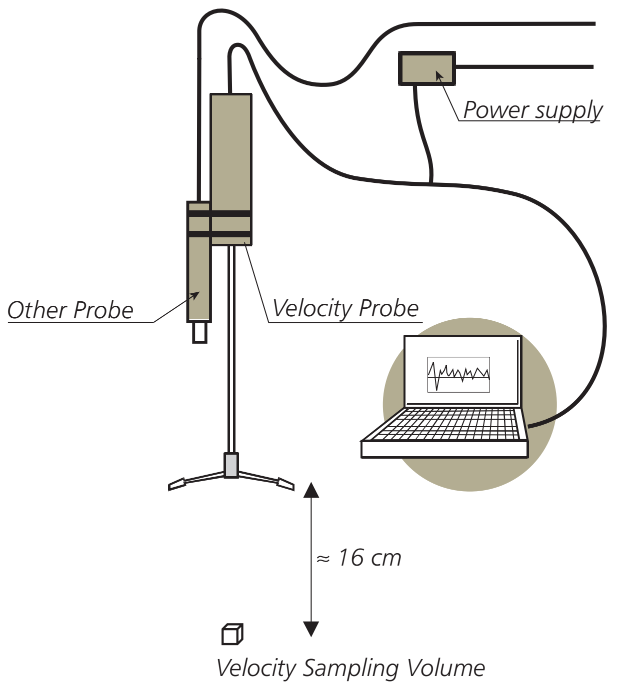


Figure 6 *The ADV measuring system.*

8. List of symbols and abbreviations

d	variance of a time series, equal to $\sigma / N^{1/2}$
f	$N - 1$; number of degrees of freedom in Student's t-distribution
t, τ	time
$t_{1-P}(f)$	Student's t-distribution
u_i, $u(t)$	momentary (measured) velocity value
x; y	coordinates in a MXS
A	cross section area
ADV	Acoustic Doppler Velocimeter
MMA	Mixing Measurement Assistance (ITT Flygt software)
GLQS	Gauss-Legendre quadrature scheme for approximating an integral with a finite sum
H	liquid depth, i.e. height of MXS
I	cf. P below
MXS	measurement cross section
N	number of measured values in a time series
P	probability that the average of a measured time series lies within a certain interval (I) around the expectation value of the underlying stochastic variable ("true value")
$R_{uu}(\tau)$	autocorrelation function of time series
T_0	autocorrelation (or macro) time scale of a time series
U	average value of a series of velocity values in a point
$<U>$	cross section average of U
U_{rms}	"root mean square" of velocity signal, close to σ for large N
W	width of MXS
WWTP	waste water treatment plant
α_i; β_j	weights defined for cross section averaging using GLQS, cf. Eq. (5.2)
ε	relative uncertainty, cf. Eq. (4.4)
ξ_i; η_j	measurement point positions defined for cross section averaging using GLQS, cf. Eq. (5.2), Fig. 1 and Table 1.
σ	standard deviation of time series, cf. Eq. (4.3)

9. References

1. *ADV Software Reference Manual*, Nortek AS (Vollen, Norway, January 2 1996); *ADV Operation Manual*, Nortek AS (Vollen, Norway, January 2 1996).
2. *User manual for MMA Mixing Measurement Assistance*, ITT Flygt AB (Solna, 2000).
3. *Handbook of mathematical functions*, National Bureau of Standards, Applied Mathematics Series 55 (November 1970); Korn G. A. & Korn T. M., *Mathematical Handbook for Scientists and Engineers*, 2nd Ed., McGraw-Hill (New York, 1968).
4. Cramér, H., *Mathematical methods of statistics*, Princeton Mathematical Series 9, Almqvist & Wiksells (USA, 1946); Blom, G. *Sannolikhetsteori och statistikteori med tillämpningar*, Studentlitteratur (Lund, 1970).

Additional reading:
Johansson, A. V., & Alfredsson, P. H. (March 1988) *Experimentella metoder inom strömningsmekaniken*. Institutionen för Mekanik, KTH, Stockholm.

10. Velocity guarantee text

"It is generally known and accepted that mixer generated flow in ditches and tanks in WWTPs is turbulent. Therefore, the velocity may assume highly varying values, and may even reverse, in a single point. At physical boundaries, the velocity vanishes, although it acts via a shear stress all the way to the boundary (wall, bottom, ...). In view of these circumstances, it is not reasonable to request a minimum velocity in a whole volume or in a whole cross section. With regard to mixing, an average, or bulk flow velocity in a cross section is a reasonable entity to prescribe.

The bulk flow velocity is measured according to ITT Flygt's Velocity Measurement Guide, as briefly outlined below:

1. A measurement cross section across the bulk flow is selected where the flow is developed and its character is unaffected by flow disturbing objects in the channel/tank.
2. A grid of measurement points, typically no less than 5 x 5, is selected using the Gauss-Legendre Quadrature Scheme. The scheme produces unevenly spaced points and the corresponding weights are unequal.
3. The magnitude of the velocity is measured in each point.
4. The sampling rate and the minimum total integration time to be used is assessed to achieve a confidence interval of ± 0.01 m/s at a confidence level of 95%. Typically some 2 minutes sampling at minimum 5 Hz rate at each point is required.
5. The total error in the measured cross section average is asserted to be ± 0.01 m/s ± the inaccuracy of the velocity probe.

ITT Flygt (name of subsidiary) guarantees that the bulk flow velocity generated by the mixer in the channel/tank under normal operating conditions (e.g. those on which the mixer design was based), to within the total error, is at least (***fill in value***) m/s."

ITT Flygt is the world’s leading manufacturer, supplier and innovator on the submersible pump, mixer and aeration markets. With production facilities in four continents our products are used everyday in wastewater treatment plants, sewage systems, aqua-agriculture, the process industry and numerous other applications. Our experience is utilised by engineers, planners and consultants to ensure reliable and cost-effective use of our systems in all corners of the world.

ITT Flygt is represented in over 130 countries and has 37 sales companies around the world.

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